Recommendations for Integrating Restoration Ecology and Conservation Biology in Ponderosa Pine Forests of the Southwestern United States

Reed F. Noss,[1,8] Paul Beier,[2] W. Wallace Covington,[3] R. Edward Grumbine,[4] David B. Lindenmayer,[5] John W. Prather,[6] Fiona Schmiegelow,[7] Thomas D. Sisk,[6] and Diane J. Vosick[3]

Abstract

Over the past century, ponderosa pine–dominated landscapes of the southwestern United States have been altered by human activities such as grazing, timber harvest, road building, and fire exclusion. Most forested areas within these landscapes now show increased susceptibility to stand-replacing fires, insect outbreaks, and drought-related mortality. Recent large wildfires in the region have spurred public interest in large-scale fuel reduction and restoration programs, which create perceived and real conflicts with the conservation of biodiversity. Conservation concerns include the potential for larger road networks, soil and understory disturbance, exotic plant invasion, and the removal of large trees in treated areas. Pursuing prescribed burning, thinning, or other treatments on the broad scale that many scientists and managers envision requires the reconciliation of ecological restoration with biodiversity conservation. This study presents recommendations from a workshop for integrating the principles and practices of restoration ecology and conservation biology, toward the objective of restoring the composition, structure, and function of dry ponderosa pine forests. Planning on the scale of hundreds of thousands of hectares offers opportunities to achieve multiple objectives (e.g., rare species protection and restoration of ecological structures and processes) that cannot easily be addressed on a site-by-site basis. However, restoration must be coordinated with conservation planning to achieve mutual objectives and should include strict guidelines for protection of rare, declining, and sensitive habitats and species.

Key words: biodiversity, conservation, ponderosa pine, restoration.

Introduction

Restoration ecology and conservation biology are distinct disciplines with somewhat different cultures, histories, norms, and methods (Young 2000). They are represented by two professional societies: the Society for Ecological Restoration International (SERI) and the Society for Conservation Biology (SCB). Although many scientists and practitioners fit equally well within the conservation biology or restoration ecology camps, many professionals from the two disciplines do not interact regularly. Membership surveys conducted by SCB in 2000 and 2004 found that, in both years, only 9% of SCB members were also members of SERI (http://conbio.net/SCB/Information/). We summarize some typical attributes of conservation planning and ecological restoration in Table 1. A comparison of the two columns in Table 1 not only shows the areas of overlap between the two fields but also the substantial areas of divergence. In this study, we focus on the challenge of integrating ecological restoration with conservation planning within landscapes dominated by dry ponderosa pine (*Pinus ponderosa*) forests in the southwestern United States.

The roots of restoration ecology can be traced back to 1938 when Aldo Leopold, John Curtis, and others at the University of Wisconsin began developing restoration treatments for establishing reference sites within the University of Wisconsin Arboretum. Restoration ecology received a boost in 1964 with the founding of the field of applied ecology and its journal, *Journal of Applied*

[1] Department of Biology, University of Central Florida, Orlando, FL 32816-2368, U.S.A.
[2] School of Forestry, Northern Arizona University, Flagstaff, AZ 86011-5018, U.S.A.
[3] Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ 86011-15017, U.S.A.
[4] Prescott College, 220 Grove Avenue, Prescott, AZ 86301, U.S.A.
[5] Centre for Resource and Environmental Studies, The Australian National University, Canberra, ACT 0200, Australia.
[6] Center for Environmental Sciences and Education, Northern Arizona University, Flagstaff, AZ 86011-5694, U.S.A.
[7] Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada, T6G 2H1.
[8] Address Correspondence to R. F. Noss, email rnoss@mail.ucf.edu

Table 1. A comparison of typical attributes of conservation planning (from the conservation biology perspective) and ecological restoration.

Conservation Planning	*Ecological Restoration*
The primary value assumption is that biodiversity and ecological integrity are good	The primary value assumption is that naturalness, ecosystem health, and ecological integrity are good
Goal is to save all the pieces (i.e., species, genetic lineages)	The overall cohesion of the "puzzle" is paramount and should conserve all the pieces
Emphasis on composition	Emphasis on structure and function
Planning focus is usually on protecting hotspots of biodiversity or endemism, and areas and species at high risk	Planning focus is usually on restoration at the ecosystem level (less at the individual species level)
Uses viability/persistence at the species level as a driver for site selection, conservation action, and measures of success	Uses reference conditions/knowledge of natural range of variability and the evolutionary context as a driver for action
Focus on maintaining what is left at species and community level	Focus on bringing the ecosystem back to historic or natural condition and restoring structure and function
Historical focus on protected areas; however, now recognizes the need for management of the landscape matrix	Often focuses more on the managed landscape matrix than on protected areas
Historical approach is to minimize human intervention or interference	Considers management as often desirable and needed; more interventionist than conservation planning
Historically, approach was usually to minimize human use of protected areas, exclude people from system	Assumes that people are part of the system; indigenous cultural practices are accepted as part of the evolutionary history
Time: Viability analyses may consider long time periods; however, short-term crisis management still drives many decisions	Time: Objective is to put the ecosystem on a trajectory of recovery that may take many human generations

Ecology, by the British Ecological Society. The first issue included themes, such as land reclamation, that are within the domain of restoration ecology (Ormerod 2003). The publication of *Restoration & Management Notes* (now called *Ecological Restoration*) starting in 1981, the founding of SERI in 1987, and the inauguration of *Restoration Ecology* in 1993 have established the field of restoration ecology as a science (Davis & Slobodkin 2004). The growing interest in the annual SERI conferences, the increasing number of papers with a restoration theme submitted to scientific journals (Ormerod 2003), and government-mandated restoration of disturbed sites demonstrate that restoration ecology has advanced rapidly in recent decades. Restoration ecology increasingly encompasses the "human dimension," placing value on societal decisions on what constitutes appropriate endpoints of restoration efforts (Allen 2003).

The term "conservation biology" was first used in 1937, in the inaugural issue of the *Journal of Wildlife Management* (Errington & Hamerstrom 1937). Conservation at that time was dominated by utilitarian objectives, such as producing game for hunting. Yet, as early as 1917, ecologists in the United States were involved in identifying remaining, relatively pristine examples of ecosystem types, hoping to secure them in nature reserves for scientific use as reference sites and for their inherent values (e.g., Shelford 1926). As noted, reference conditions were also recognized as important in the early history of restoration ecology. The SCB was founded in 1985 and, in 1987, initiated its journal *Conservation Biology*. SCB currently has more than 8,000 members organized into regional sections across the world. The mission of SCB includes the encouragement of "communication and collaboration between conservation biology and other disciplines (including other biological and physical sciences, the behavioral and social sciences, economics, law, and philosophy) that study and advise on conservation and natural resources issues" (http://conbio.net/SCB/Information/Mission/).

Both restoration ecology and conservation biology recognize that the degradation of nature poses threats to ecosystem sustainability. The concept of the evolutionary environment, which shaped adaptation of the native biota, is central to both. The increasing emphasis on natural disturbance regimes and ecosystem processes and functions, in addition to structure and composition, in planning offers an ideal opportunity to bridge the two disciplines in their application to real-world problems.

An integration of restoration ecology and conservation biology is urgently needed in the ponderosa pine forests of the southwestern United States. The current condition of these forests is the manifestation of a century of fire suppression, livestock grazing (which, among other problems, reduces the accumulation of herbaceous fuels necessary to carry frequent, low-severity fires), timber harvesting, road building, the introduction of invasive exotic plants, and other human activities. These activities in combination have created forests that are often highly susceptible to uncharacteristic stand-replacing fire, drought, insect attack, and other deviations from historic conditions (Covington & Moore 1994; Covington et al. 1997; Allen et al. 2002; Friederici 2003; Moore et al. 2004). The Mogollon Plateau of central Arizona contains the largest continuous ponderosa pine forest (Cooper 1960). In 2002, the Rodeo-Chediski Fire burned almost 200,000 ha in the central Mogollon Plateau, including almost 500 homes. The western Mogollon Plateau, which has landscape-scale fuel loads similar to those that fed the Rodeo-Chediski fire, includes the cities of Flagstaff and Williams and numerous unincorporated developments, extensive public lands, and prime wildlife habitat. Furthermore, it provides critical water supplies and recreation opportunities for people, including those from the populous cities of central Arizona.

With increases in the area affected by wildfires in this region and across much of the West, citizens, policymakers, and some scientists are calling for a radical increase in the size and number of treatments to reduce fuel loads, thereby reducing the probability of stand-replacing fires and the potential for loss of human life and property. One major and controversial response to these concerns is the Healthy Forests Restoration Act of 2003, a law with potentially wide-ranging consequences for western forests because it mandates restoration mainly in the form of fuel-reduction treatments. Large-scale treatments, when warranted, must be implemented on the basis of the best available scientific information and guidance. Some projects may conflict with efforts to protect habitat for imperiled species (Allen et al. 2002; DellaSala et al. 2004) as well as with the public's interest in recreation, aesthetics, and wilderness values. Conservationists are legitimately concerned about timber harvest, road building, soil and understory disturbance, exotic plants, and loss of key habitats on treated sites. In response to these and other concerns, and to provide scientific support for prudent restoration and hazardous fuel actions, the Southwest Forest Health and Wildfire Prevention Act of 2004 establishes ecological restoration institutes at universities in Arizona, New Mexico, and Colorado.

Remaining old trees within unnaturally dense stands of post-settlement trees are at increased risk of stand-replacing fire. In such cases, the threats posed by lack of action may be greater than risks associated with legitimate restoration. Fortunately, unlike the situation in many other forest types (Veblen 2003; Brown et al. 2004), in dry ponderosa pine forests efforts to reduce fuel loads and associated risks to human communities may be largely compatible with ecological restoration goals (Schoennagel et al. 2004). Nevertheless, as restoration or fuel-reduction programs are expanded from stands to landscapes, the linkage of ecological restoration with conservation planning becomes more urgent because the ecological integrity (Pimentel et al. 2000) of larger areas is at stake.

This study presents findings from a workshop at Northern Arizona University on 20–22 July 2004, which addressed the potential for integrating ecological restoration and conservation planning for ponderosa pine ecosystems of the Mogollon Plateau. Ongoing efforts by the Ecological Restoration Institute (http://www.eri.nau.edu) through the ForestERA project (http://www.forestera.nau.edu) in the region provide tools and data for large-scale planning (Hampton et al. 2003; Sisk et al. 2004) and opportunities for the integration of restoration and conservation objectives. We do not offer explicit guidelines for restoring ponderosa pine forests here but rather identify and discuss the biodiversity-related issues involved in such restoration. We start from the premise that both ecological restorationists and conservation biologists want to protect and restore biodiversity and ecological integrity. We then discuss how these fields might be reconciled with respect to southwestern ponderosa pine ecosystems.

Workshop Recommendations for Recovery of Southwestern Ponderosa Pine Ecosystems

The fire ecology and management of southwestern ponderosa pine forests are of high public interest. Public concern about catastrophic fire risk, wildlife habitat, and other issues cannot be addressed without the integration of conservation and restoration. We summarize our recommendations on integration as follows.

Think Big—Plan Conservation and Restoration Projects on Landscape and Regional Scales

Resolving conflicting goals in ecosystem management becomes easier as the spatial scale of the planning region expands. At the scale of a few hectares, where the needs of imperiled species may conflict not only with each other but also with general objectives for restoration of vegetation structure, finding a win–win solution may be impossible. Planning on a broad spatial scale facilitates multiobjective management and may allow seemingly irreconcilable goals to be met. For example, high-quality habitat for the Mexican spotted owl (*Strix occidentalis lucida*) is much denser than the open-canopied, park-like forest often considered the restoration ideal for southwestern ponderosa pine ecosystems (Beier & Maschinski 2003). Fire rarely burns homogeneously across a landscape, however, and often leaves a mosaic with denser stands retained in such areas as north-facing slopes and steep canyons and where erratic weather reverses the wind direction and fire intensity. On a landscape scale, restoring a natural fire regime can result in a range of stand conditions, including dense stands with abundant snags and woody debris. Therefore, restoring a stand-maintenance fire regime (i.e., low severity but frequent fire) over large portions of the landscape could be done without eliminating the habitat for Mexican spotted owls (ForestERA, unpublished data) and could benefit the owl by reducing the probability that high-severity fire will eliminate the dense but scattered stands that serve as the prime habitat.

High-severity fires in southwestern ponderosa pine forests are increasing in frequency and spatial extent after decades of active and passive fire exclusion (Covington 2003). Because the landscape shifts toward larger and potentially more homogeneous patches after severe fires, or toward alternative recovery states such as unnaturally dense stands or nonforest communities, as recent evidence suggests (Savage & Mast 2005), conflicts with biodiversity conservation and restoration objectives are obvious.

Management approaches are needed that maintain or restore forest biodiversity at multiple spatial scales (Lindenmayer & Franklin 2002). The appropriate management of each site can only be determined by considering the attributes of the site within the broader landscape context (Noss & Harris 1986).

Manage Each Forest Landscape within Its Characteristic Range of Variability

To achieve conservation and restoration objectives simultaneously, forest managers should strive to emulate the natural range of variability in conditions, including the patchiness of the landscape on a variety of spatial scales (Landres et al. 1999; Moore et al. 1999; Swetnam et al. 1999; Allen et al. 2002). This characteristic range of variability will differ from place to place within and among regions because forest landscapes are tremendously variable in composition, structure, and function. Policymakers and the public need to be educated on this fact because they often assume that all forests are the same and require the same type of management (DellaSala et al. 2004). Restorationists and conservationists working in dry ponderosa pine ecosystems need to be cautious not to extrapolate their recommendations beyond their system (Johnson et al. 2001). For example, Schoennagel et al. (2004:662) warn

> Ecological restoration and fire mitigation are urgently needed in dry ponderosa pine forests, where previous research supports this management action. However, we are concerned that the model of historical fire effects and 20th-century fire suppression in dry ponderosa pine forests is being applied uncritically … including places where it is inappropriate ….

Natural variability in structure often can be addressed by using reference conditions (historical/retrospective or existing natural areas) to guide prescriptions (Moore et al. 1999; Friederici 2003). A variety of restoration approaches (e.g., various combinations of thinning and burning treatments) should be used to spread the risk of failure of any one approach. Managers should not implement the same treatment everywhere, even within the same landscape and forest type.

The issue of whether a strict "diameter cap" (i.e., a diameter limit above which trees cannot be cut) should be imposed for restoration or fuel-reduction treatments is controversial. We do not believe a "one-size-fits-all" diameter cap is any more justifiable scientifically than a one-size-fits-all restoration strategy. Although cutting of old trees always should be avoided, because they have been severely depleted since European settlement (Allen et al. 2002), it should be recognized that stands differ in their history (e.g., the date when fire exclusion began) and site conditions. Thus, a diameter cap that is sensible in one stand may not be in another.

The social dimensions of land management inevitably influence decision-making, and this influence is particularly evident with respect to diameter caps. In cases where public opposition to the cutting of large trees threatens to delay or scuttle restoration actions, a diameter cap may allow critical management actions to proceed in a timely manner. In such cases, caps should be sufficiently large so that they do not inhibit legitimate treatment options, not just for restoring patches of trees but also for restoring grassy openings within the forest, while small enough to assure protection of existing old trees without interfering with the rapid tree growth needed to provide replacement old trees. Wherever possible, we suggest that the laudable goals of protecting existing old growth (the conservation objective) and restoring old-growth conditions and processes (the restoration objective) be addressed directly, e.g., through polices that require close involvement of qualified scientists in the planning and implementation of treatments and adherence to environmental laws.

Recognize That Salvage Logging Is Not Restoration

By restoration, we mean guiding an ecosystem along a trajectory of recovery of natural structure, function, and composition, that is, toward ecological health and integrity (Franklin et al. 1981; Noss 1990; Pimentel et al. 2000; Covington 2003). A popular belief among nonscientists is that salvage logging is often necessary to help ecosystems heal. Except in extreme cases, however, ecosystems usually recover naturally after fires, and often the pace of recovery is much faster than anticipated (Turner et al. 2003). Salvage logging can undermine the ecological benefits of fire and reduce prospects for ecosystem recovery (Lindenmayer et al. 2004). Studies of the Rodeo-Chediski fire suggested that several kinds of treatments, including salvage logging, were effective in reducing fire severity and spread (Wilmes et al. 2002; Schoennagel et al. 2004). Interpretation of the results of this study is problematic, however, because sampling did not control for the effects of fire-suppression efforts or daily weather and in general was not consistent with statistical requirements for experimental design (Rhodes & Odion 2004). In rare cases, the careful removal of woody material to reduce intense reburn potential and improve restoration potential in forests that have experienced uncharacteristic stand-replacement fires may be justified, but salvage logging is not restoration and often has countervailing effects.

Restoration Should Respect Roadless Areas

A potential conflict exists between conservationists and those advocating for mechanical fuel-reduction treatments regarding roads and roadless areas. Roadless areas often have high value for conservation of biodiversity (Noss & Cooperrider 1994; Strittholt & DellaSala 2001). For example, they serve as refugia for sensitive terrestrial and aquatic species, reduce invasions of non-native species, and provide reference conditions for management experiments. They are more representative of natural landscapes than formally protected areas (DeVelice & Martin 2001; Strittholt & DellaSala 2001). The deleterious impacts of roads on wildlife and ecosystems are abundantly documented (Trombulak & Frissell 2000). For example, there is a close connection between roads and non-native species (e.g., Tyser & Worley 1992; Gelbard & Belnap 2003). Invasive non-native plants often change fire regimes and influence the efficacy of restoration treatments (Brooks et al. 2004). Roads serve as unnatural firebreaks and, conversely, as sources of ignitions (Cardille et al. 2001; Chou et al. 1993). They also provide access to humans, increasing the potential for recreational uses to affect biodiversity adversely.

It is often assumed without justification that roads are required to conduct restoration and other active management. Ecological restoration should not be used as an excuse to build new roads or keep existing roads open indefinitely. Indeed, the reduction of road density across the landscape may be essential for comprehensive ecological restoration, which would include reintroduction of carnivores and other species that are sensitive to the access provided by roads (Noss et al. 1996). The potential conflict between conservation and hazardous fuel reduction objectives with respect to roadless areas might be addressed simply by requiring that restoration activities be implemented without the construction of new roads. Intelligent use of topographic features and attention to climatic conditions might allow many restoration objectives to be met using prescribed fire alone. Even unmanaged fire in roadless areas may result in significant restoration gains under specific conditions (Fulé et al. 2003). We agree with other ecologists (e.g., DellaSala & Frost 2001) that roadless areas require special attention in developing restoration prescriptions because many of their conservation values would be compromised by road-based mechanical fuel treatments. In roaded areas, especially near towns and other critical landscape elements at risk of severe fire damage, more-intensive treatments may be appropriate; however, managers should exercise caution to minimize soil disturbance during restoration and should shut down, reclaim, and revegetate undesirable roads after treatments. Given the staggering costs of road maintenance and current budget constraints on management of public lands, combined with the push of some elected officials for road building in roadless areas, this is an opportune time to reexamine this issue objectively.

Recognize That Protected Areas May Require Active Management

Protected areas are cornerstones of conservation (Noss et al. 1999) and restoration (Covington 2003), albeit they will seldom be sufficient (Lindenmayer & Franklin 2002). A conservation area design that includes identification of core areas should be a central component of landscape-scale restoration planning. Protected areas are conventionally thought of as places where human impacts (including management) are kept to a minimum. When forest communities that are naturally characterized by frequent fire are fire suppressed, however, they may lose the qualities for which they were set aside.

Because the effects of fire exclusion and other human activities are widespread in southwestern ponderosa pine forests, protected areas such as wilderness areas, national parks, and natural areas should not automatically be excluded from consideration for treatments such as prescribed burning or thinning. This is a controversial issue with many in the conservation community strongly opposed to any active management within reserves. This distrust of management intervention is understandable in that some managers have been motivated by political and economic interests at the expense of biodiversity protection. Furthermore, treatments within some reserves would be imprudent and unnecessary. For example, a disproportionate number of protected areas are at high elevation (Scott et al. 2001) and contain forest types, such as moist mixed conifer and subalpine forests, that burn less frequently and, therefore, have not suffered from fire exclusion as have low-elevation types (Brown et al. 2004; Schoennagel et al. 2004). On the other hand, protected areas that contain dry ponderosa pine and other forest types characterized by frequent, stand-maintaining fires often require management to restore and sustain their natural condition.

We recommend that treatments in ponderosa pine–dominated reserves be of the minimal intensity needed to restore grassy understories and protect old trees and imperiled species habitat. A treatment in one reserve should not be viewed as a precedent for similar treatments in other reserves. Given the foregoing discussion, it seems prudent that no new roads should be built within protected areas to accommodate restoration treatments. Once restored, if reserves are sufficiently large (e.g., expanded through road closures), they may be able to incorporate an unmanaged natural disturbance regime (Pickett & Thompson 1978; Noss & Cooperrider 1994). Because variability in landscape conditions is desirable for scattering risks of management uncertainty—and because we do not fully understand the impacts of restoration and management—some proportion of protected areas should be exempt from active management, at least for now. These exempt areas will provide insurance against management mistakes and can serve as comparison areas for adaptive management. Similar to restoration fuel breaks used to protect human communities from severe wildfire, thinning and burning of buffer zones upwind or adjacent to wilderness boundaries in some cases may reduce the probability of uncharacteristic stand-replacing fires occurring inside.

Restoration Strategy Should Encompass Wildlands and the Wildland–Urban Interface

There is widespread agreement among policymakers, many environmental groups, and communities for focusing fuel-reduction treatments in the wildland–urban interface (Southwest Forest Alliance 2002). Less support exists for treatments in the wildlands (Solop 2003). The rapidly expanding human population, especially urban sprawl into surrounding wildlands, is the primary factor confounding fire-management policies in the American West (Dombeck et al. 2004). We recommend that county-level and urban planning explicitly take into account the fire risks in the wildland–urban interface and limit development in fire-prone areas (Marzluff & Bradley 2003).

From a regional restoration perspective, managing the wildland–urban interface versus managing wildlands is a false dichotomy—they are parts of the same landscapes. For example, they are often within the same watersheds and provide habitat for the same populations. Nevertheless, intensive fuel-reduction treatments, fire suppression, and other management practices that would not be appropriate in wildlands may be appropriate in the wildland–urban interface because of the premium placed on protecting human lives and property (DellaSala et al. 2004).

Conclusions

Our conclusions represent the collective opinion of the scientists who participated in this effort to reconcile ecological restoration and conservation planning within the context of the political debate surrounding the management of southwestern ponderosa pine forests. We suggest that the integration of concepts, principles, and methods of conservation planning and ecological restoration provides a scientifically rigorous basis for managing ponderosa pine landscapes for the recovery of a natural range of variability in structure and function, while saving all the pieces (i.e., composition). The scientific basis for moving forward with landscape-scale restoration and conservation is solid, even if many questions remain about the efficacy of particular techniques. Available evidence indicates that planning should occur on a regional scale in order to integrate and reconcile multiple objectives (e.g., biodiversity conservation and restoration of ecosystem health). It is also evident that a variety of restoration treatments should be used to spread the risk of failure of any one approach and that a "one-size-fits-all" approach to forest restoration is inappropriate. Such an active adaptive management approach is sensible, but only if pursued rigorously with a valid experimental design and monitoring plan, and including the comparative testing of multiple hypotheses. Reducing road density across the landscape and protecting the remaining old trees from logging, unnatural stand-replacing fire, and uncharacteristic levels of insect and disease attack are perhaps the most needed conservation measures. Such measures will increase the likelihood that biodiversity will persist into a restored state, when natural fire regimes and informed management complete the integration of restoration and conservation.

Acknowledgments

We thank the Ecological Restoration Institute, the ForestERA Project, and the Northern Arizona University for hosting the workshops that led to this study. We thank E. Aumack, T. McKinnon, M. Clark, and T. Schulke for their comments on the report that preceded this study. We thank P. Friederici and two anonymous referees for valuable comments on the submitted draft. Thanks also to S. Singh for editorial assistance.

LITERATURE CITED

Allen, C. D., M. Savage, D. A. Falk, K. F. Suckling, T. W. Swetnam, T. Schulke, P. B. Stacey, P. Morgan, M. Hoffman, and J. T. Klingel. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective. Ecological Applications **12:**1418–1433.

Allen, E. B. 2003. New directions and growth of restoration ecology. Restoration Ecology **11:**1–2.

Beier, P., and J. Maschinski. 2003. Threatened, endangered, and sensitive species. Pages 306–327 in P. Friederici, editor. Ecological restoration of southwestern ponderosa pine forests. Island Press, Washington, D.C.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Kelley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of alien plants on fire regimes. BioScience **54:**677–688.

Brown, R. T., J. K. Agee, and J. F. Franklin. 2004. Forest restoration and fire: principles in the context of place. Conservation Biology **18:**903–912.

Cardille, J. A., S. J. Ventura, and M. G. Turner. 2001. Environmental and social factors influencing wildfires in the Upper Midwest, United States. Ecological Applications **11:**111–127.

Chou, Y. H., R. A. Minnich, and R. A. Chase. 1993. Mapping probability of fire occurrence in the San Jacinto Mountains, California. Environmental Management **17:**129–140.

Cooper, C. F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecological Monographs **30:**129–164.

Covington, W. W. 2003. The evolutionary and historical context. Pages 26–47 in P. Friederici, editor. Ecological restoration of southwestern ponderosa pine forests. Island Press, Washington, D.C.

Covington, W. W., P. Z. Fulé, M. M. Moore, S. C. Hart, T. E. Kolb, J. N. Mast, S. S. Sackett, and M. R. Wagner. 1997. Restoring ecological health in ponderosa pine forests of the Southwest. Journal of Forestry **95:**23–29.

Covington, W. W., and M. M. Moore. 1994. Southwestern ponderosa pine forest structure: changes since European settlement. Journal of Forestry **92:**39–47.

Davis, M. A., and L. B. Slobodkin. 2004. The science and values of restoration ecology. Restoration Ecology **12:**1–3.

DellaSala, D. A., and E. Frost. 2001. An ecologically based strategy for fire and fuels management in national forest roadless areas. Fire Management Today **61:**12–23.

DellaSala, D. A., J. E. Williams, C. D. Williams, and J. F. Franklin. 2004. Beyond smoke and mirrors: a synthesis of fire policy and science. Conservation Biology **18:**976–986.

DeVelice, R. L., and J. R. Martin. 2001. Assessing the extent to which roadless areas complement the conversation of biological diversity. Ecological Applications **11:**1008–1018.

Dombeck, M. P., J. E. Williams, and C. A. Wood. 2004. Wildfire policy and public lands: integrating scientific understanding with social concerns across landscapes. Conservation Biology **18:**883–889.

Errington, P. L., and F. N. Hamerstrom. 1937. The evaluation of nesting losses and juvenile mortality of the ring-necked pheasant. Journal of Wildlife Management **1:**3–20.

Franklin, J. F., K. Cromack, W. Denison, A. Mckee, C. Maser, J. Sedell, F. Swanson, and G. Juday. 1981. Ecological characteristics of old-growth Douglas-fir forests. General Technical Report PNW-118. USDA Forest Service, PNW Forest and Range Experiment Station, Portland, Oregon.

Friederici, P., editor. 2003. Ecological restoration of southwestern ponderosa pine forests. Island Press, Washington, D.C.

Fulé, P. Z., A. E. Cocke, T. A. Heinlein, and W. W. Covington. 2003. Effects of an intense prescribed forest fire: is it ecological restoration? Restoration Ecology **12:**220–230.

Gelbard, J. L., and J. Belnap. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. Conservation Biology **17:**420–432.

Hampton, H. M., Y. Xu, J. W. Prather, E. N. Aumack, B. G. Dickson, M. M. Howe, and T. D. Sisk. 2003. Spatial tools for guiding forest restoration and fuel reduction efforts. CD-ROM. Proceedings of the 2003 ESRI Users Conference. San Diego, California.

Johnson, E. A., K. Miyanishi, and S. R. J. Bridge. 2001. Wildfire regime in the boreal forest and the idea of suppression and fuel buildup. Conservation Biology **15:**1554–1557.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications **9:**1179–1188.

Lindenmayer, D. B., and J. F. Franklin. 2002. Conserving forest biodiversity: a comprehensive multiscaled approach. Island Press, Washington, D.C.

Lindenmayer, D. B., D. R. Foster, J. F. Franklin, M. L. Hunter, R. F. Noss, F. A. Schmiegelow, and D. Perry. 2004. Saving forests or saving fiber? Salvage harvesting policies after natural disturbance impairs ecosystem and species recovery. Science **303:**1303.

Marzluff, J. M., and G. A. Bradley. 2003. Ecological restoration in the urban-wildland interface. Pages 353–370 in P. Friederici, editor. Ecological restoration of southwestern ponderosa pine forests. Island Press, Washington, D.C.

Moore, M. M., W. W. Covington, and P. Z. Fulé. 1999. Evolutionary environment, reference conditions, and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications **9:**1266–1277.

Moore, M. M., D. W. Huffman, P. Z. Fulé, W. W. Covington, and J. E. Crouse. 2004. Comparison of historical and contemporary forest structure and composition on permanent plots in southwestern ponderosa pine forests. Forest Science **50:**162–176.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology **4:**355–364.

Noss, R. F., and A. Cooperrider. 1994. Saving nature's legacy: protecting and restoring biodiversity. Defenders of Wildlife and Island Press, Washington, D.C.

Noss, R. F., Dinerstein, E., B. Gilbert, M. Gilpin, B. Miller, J. Terborgh, and S. Trombulak. 1999. Core areas: where nature reigns. Pages 99–128 in M. E. Soulé and J. Terborgh, editors. Continental conservation: scientific foundations of regional reserve networks. Island Press, Washington, D.C.

Noss, R. F., and L. D. Harris. 1986. Nodes, networks, and MUM's: preserving diversity at all scales. Environmental Management **10:**299–309.

Noss, R. F., H. B. Quigley, M. G. Hornocker, T. Merrill, and P. Paquet. 1996. Conservation biology and carnivore conservation. Conservation Biology **10:**949–963.

Ormerod, S. J. 2003. Restoration in applied ecology: editor's introduction. Journal of Applied Ecology **40:**44–50.

Pickett, S. T. A., and J. N. Thompson. 1978. Patch dynamics and the design of nature reserves. Biological Conservation **13:**27–37.

Pimentel, D., L. Westra, and R. F. Noss. 2000. Ecological integrity: integrating environment, conservation, and health. Island Press, Washington, D.C.

Rhodes, J. J., and D. C. Odion. 2004. Evaluations of the efficacy of forest manipulations still needed. BioScience **54:**980.

Savage, M., and J. N. Mast. 2005. How resilient are southwestern ponderosa pine forests after crown fires? Canadian Journal of Forest Research **35:**967–977.

Schoennagel, T., T. T. Veblen, and W. H. Romme. 2004. The interaction of fire, fuels, and climate across Rocky Mountain forests. BioScience **54:**661–676.

Scott, J. M., F. W. Davis, R. G. McGhie, R. G. Wright, C. Groves, and J. Estes. 2001. Nature reserves: do they capture the full range of America's biological diversity? Ecological Applications **11:**999–1007.

Shelford, V. E., editor. 1926. Naturalist's guide to the Americas. Williams and Wilkins, Baltimore, Maryland.

Sisk, T. D., H. M. Hampton, J. W. Prather, E. N. Aumack, Y. Xu, M. R. Loeser, T. Munoz-Erickson, and J. Palumbo. 2004. Forest Ecological Restoration Analysis (ForestERA) Project Report, 2002–2004. Center for Environmental Sciences and Education, Northern Arizona University, Flagstaff.

Solop, F. 2003. Grand Canyon poll: a survey to assess public attitudes towards forest health and management. Social Research Lab, Northern Arizona University, Flagstaff (available from http://www4.nau.edu/srl/News.aspx?Year = 2003) accessed December 14, 2005.

Southwest Forest Alliance. 2002. Public opinion on forest management in Arizona. Poll prepared by the Behavior Research Center. Phoenix, Arizona.

Strittholt, J. R., and D. A. DellaSala. 2001. Importance of roadless areas in biodiversity conservation in forested ecosystems: a case study—Klamath-Siskiyou ecoregion, U.S.A. Conservation Biology **15:** 1742–1754.

Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications **9:**1189–1206.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology **14:**18–30.

Turner, M. G., W. H. Romme, and D. B. Tinker. 2003. Surprises and lessons from the 1988 Yellowstone fires. Frontiers in Ecology and Environment **1:**351–358.

Tyser, R. W., and C. A. Worley. 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (USA). Conservation Biology **6:**253–262.

Veblen, T. T. 2003. Historic range of variability of mountain forest ecosystems: concepts and applications. Forestry Chronicle **79:** 223–226.

Wilmes, L. D., Martinez, L. Wadleigh, C. Denton, and G. Geisler. 2002. Apache-Sitgreaves National Forests Rodeo-Chediski Fire Effects Summary. Apache-Sitgreaves National Forests, Springerville, Arizona.

Young, T. P. 2000. Restoration ecology and conservation biology. Biological Conservation **92:**73–83.